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A METHOD OF ESTIMATING ABUNDANCE OF GROUNDFISH ON GEORGES BANK

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ABSTRACT

A method is developed for computing a standardized catch per fishing day for otter-trawl vessels to use in estimating abundance. It is shown that the fishing effort can be classified by the depth at which the fishing is conducted. From trips caught wholly in one depth zone the comparative abundance in shallow, medium, and deep water (0–30, 31–60, and more than 60 fathoms) has been determined for the 13 principal species. It is shown that for most of these species an estimate of their abundance requires the treatment of fishing effort by depth categories.

CONTENTS

A METHOD OF ESTIMATING ABUNDANCE OF GROUNDFISH ON GEORGES BANK

By GEORGE A. ROUNSEFELL, *Fishery Research Biologist*

In studying the fluctuations in abundance of various species that comprise the catch, it is of paramount importance to know how the abundance of each species usually varies from bank to bank and from depth to depth. When vessels are fishing chiefly for a particular species, they seek the grounds and the depths at which that species is most easily taken in abundance. For such a species, the catch per unit of fishing effort will measure the relative abundance with considerable accuracy, since the vessels will shift to grounds and depths yielding the highest catches. For other species, however, the fluctuations in actual abundance cannot be measured without sufficient knowledge of their average relative density in different depths and on different grounds. Therefore, a study of the distribution of these other species by depth and fishing grounds is a necessary preliminary to a study of their annual fluctuations in abundance.

Knowledge of the relative density of each species by fishing grounds is of considerable value from other standpoints. What effect is a fishery in any certain area likely to have on the stock of each species? In certain cases the question arises: What effect will a change in the size of the mesh of the trawl have on the catches? Only by knowing the density of each species by areas and depths can these questions be answered.

For many species not extensively sought for economic reasons, it is desirable to know whether there is a possibility of the catch being increased, should it become desirable to increase production. There is also the problem whether the range of a species is wholly covered by the fishery or may extend to areas beyond.

The methods developed in this paper have been followed by the haddock investigation of the North Atlantic Fishery Investigations in computing indexes of abundance from 1931 to 1953.

MATERIAL

To obtain a measure of the relative density of each species it was necessary to ascertain the quantity caught by certain units of fishing effort. Collection of the data necessary for this study was started in the fall of 1931, at the Boston Fish Pier, and is continuing. In 1942 this collection was extended to the ports of Gloucester and New Bedford, Mass.; in 1953 it was extended to Provincetown, Mass., and Rockland and Portland, Maine. A full description of the methods of collection is given by Rounsefell (1948).

The essential data collected for each vessel interviewed are as follows:

1. Name of the vessel, and type of gear employed.
2. Day and hour of departure and of arrival at port.
3. Positions fished, by "unit" areas, each unit comprising a rectangle of 10′ of latitude and 10′ of longitude, or about 10 miles by 7-plus miles.
4. Depth, in fathoms, at each fishing position.
5. Estimated amount of the catch, in thousands of pounds, at each fishing position.
6. Estimated proportion of each species taken on different fishing grounds.
7. For line-trawl vessels, the number of tubs of gear set out at each fishing location.
8. For otter-trawl vessels, an estimate of the time spent on each fishing ground.
9. For otter-trawl vessels, the total amount of time lost on the trip (other than the usual running time to and from the banks) because of such occurrences as torn nets, engine trouble, or stormy weather.

CALCULATION OF CATCH PER FISHING DAY FOR OTTER-TRAWL VESSELS

In order to obtain for otter-trawl vessels a measure of fishing effort more or less independent of weather, distance traveled . . ., it was found desirable to calculate the amount of time the vessel actually spent in fishing while on the fishing grounds. From the data available, the actual number of days the vessel was absent from port was calculated to the nearest tenth of a day. The time spent away from port was consumed partly in the voyage to and from the bank. To discount this, the groups of otter-trawl vessels selected for study were questioned about their average speed under working conditions, and in many cases this was checked for various voyages by means of radio reports. Tables were made to show the time (to the nearest tenth of a day) that it would take a vessel to make the trip from port to each statistical subarea (see fig. 1.) at the average speed of the selected group. The time the vessel was absent from port, minus this running time, and also minus any time lost by bad weather, . . ., gave the calculated number of fishing days for each trip. On the average, these calculated fishing times were found to agree with the estimated fishing times obtained from the interviews but they were used instead of the estimated times given in the interviews because they were considered less subject to personal judgment.

In the preceding calculations, the distance was measured from port to a point in the subarea empirically selected as being nearest to the average position fished in that subarea (as shown by plots of many fishing positions over several years). When the vessel fished in two subareas that extended in the same direction from port, only the voyage to and from the most distant of the two subareas was used. When more than one subarea was fished and the subareas were not in line, the running time was taken from port to one subarea, then between subareas, and finally from the last subarea back to port.

When a vessel fished in more than one subarea, the calculated fishing time was divided between the subareas in the same proportion as the estimated fishing time given in the interview, except that when the estimated and calculated times did not agree and the estimated time in a certain subarea was only 1 day or a fraction of a day, this estimated time was considered correct, and adjustment was made in the time for the subarea or subareas in which more fishing was conducted. Although this approach is not easily susceptible of statistical proof, it is obvious that the estimates of the shorter periods of time are much more apt to be correct than those of the longer periods. A mate may easily be uncertain whether they fished 6 days or 7 days in a subarea, but an estimate of 12 hours is seldom far off.

In some cases, the mate did not remember the number of hours spent in a subarea in which the vessel did little fishing but knew the number of tows made by the otter trawl. In these cases, each tow was considered as an estimated one-tenth of a fishing day. This estimate is predicated on the number of tows per day by large otter trawls, as indicated by careful notes and logs kept by several vessels for W. C. Herrington. These data showed that on the average there were 10 tows per day.

SELECTION OF OTTER-TRAWL VESSELS FOR DETERMINING RELATIVE ABUNDANCE

The first step in obtaining the catch per day was to select two groups of Boston otter trawlers, each group fairly homogeneous with respect to size of vessels. The first group of 12 large (over 150 gross tons) otter trawlers ranged in size from 163 to 173 gross tons, with an average of 167 gross tons. The second group of 13 vessels ranged from 229 to 262 gross tons, with an average of 247 gross tons, or 48 percent larger than the first group in average size. However, after the data on catch per day were tabulated, it was found that the selection of these groups on the basis of gross tonnage was apparently erroneous. In order to decide on the proper basis for selection, all 25 boats were compared for the year 1938.

The levels of fish abundance differ considerably between the New England and Nova Scotia banks; therefore the comparison of fishing ability was confined to the New England banks, which accounted for 57 percent of the season's catch.

In making this comparison, it was found that some of these boats did considerable fishing for ocean perch, while others did little or none. As this is a specialized fishery that yields a far greater poundage per unit of fishing effort, it was necessary to eliminate this cause of variability in order to obtain a valid comparison. Tabulation of the 146 trips or portions of trips made in the deep waters (more than 60 fathoms) of Subareas XXII, F, G, and H in which ocean perch were taken, showed 72 instances in which over 80 percent of the catch consisted of ocean perch; these trips averaged 95 percent ocean perch. Another 29 trips had between 41 and 80 percent ocean perch and averaged 58 percent, and 45 trips had from 1 to 40 percent ocean perch and averaged 16 percent. Obviously, on the trips with a high percentage of ocean perch

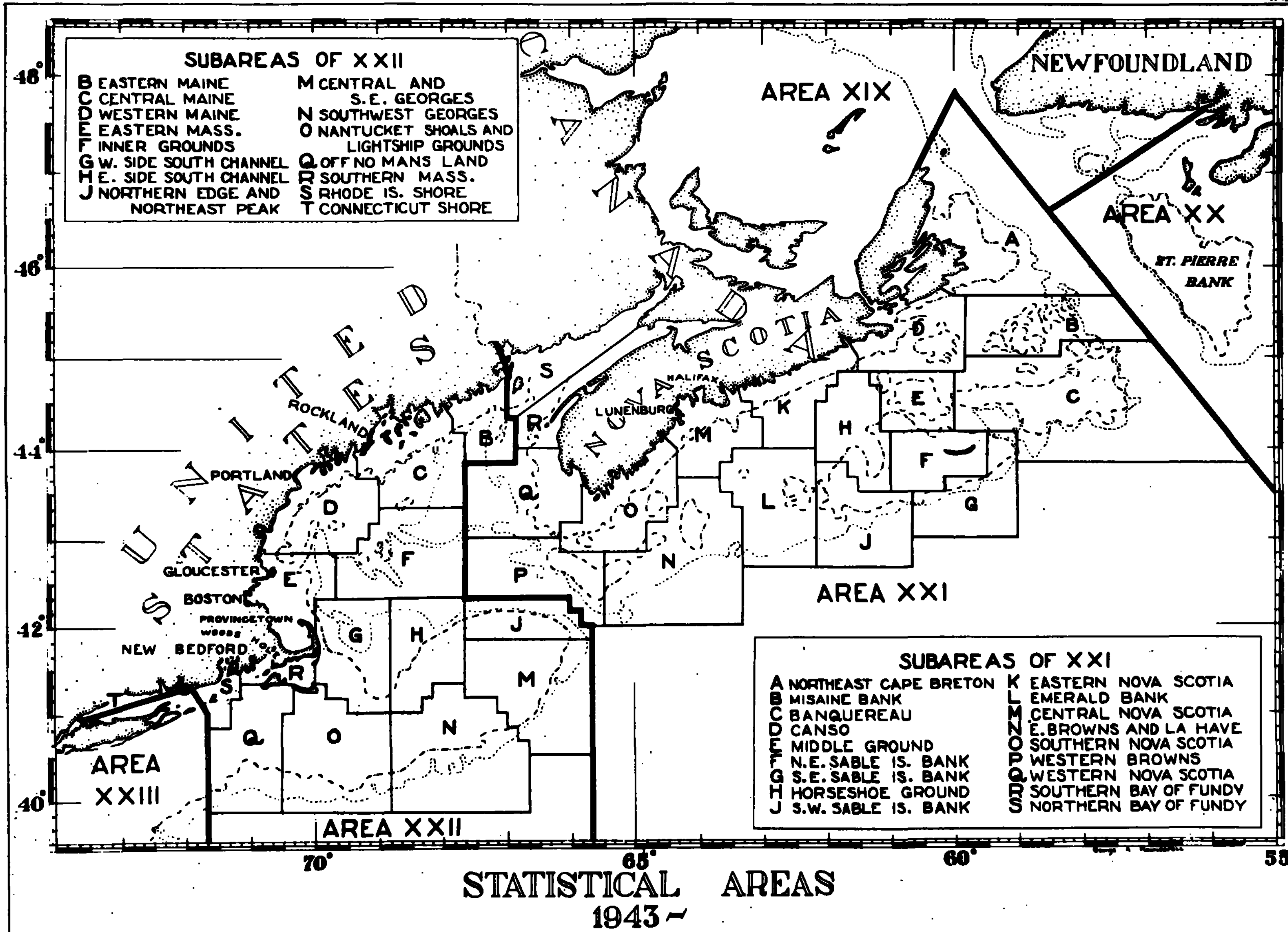

FIGURE 1.—Statistical areas in current use for reporting catches of fish in the North Atlantic. These areas are the result of careful study of fishing grounds, and are a westward extension (sanctioned by the North American Council of Fishery Investigations) of the international areas established in European waters by the International Council for the Exploration of the Sea.

the vessels had spent all or a large portion of their time seeking this species. Therefore, all trips consisting of over 40 percent ocean perch were eliminated from the comparison. This amounted to less than 10 percent of the catch in Area XXII.

The coefficient of correlation between the average catch per day of the 25 vessels and their gross tonnages, +0.4033, was not statistically significant. What correlation exists is undoubtedly due to the linkage of gross tonnage to other factors, treated below.

Since these vessels all employ the same type and size of otter trawl, regardless of differences in the sizes of the vessels, the absence of a significant correlation between size of vessel and fishing ability is not surprising. Obviously, more important factors are the amount of sea bottom covered by the net at each tow and the number of tows made each day.

The amount of ground covered in a tow will depend largely on the speed and power of the vessel. Therefore, the catch per day was correlated with the power of the vessels. Instead of correlating catch per day directly with horsepower, the ratio of horsepower to length was used as the criterion of power, since the horsepower of a vessel depends more on length than on tonnage. Also, the use of horsepower directly, instead of the ratio, does not give a true estimate of towing ability. This correlation gave a statistically significant coefficient of correlation of +0.75.

Since the newer vessels take advantage of all improvements in design and usually obtain the best crews, it was suspected that age of the vessel might play a part. The correlation of age of vessel and catch per day gave a significant coefficient of −0.6643, showing that the newer vessels were superior.

However, as the newer vessels were often better powered than the older vessels, it was necessary to eliminate the effect of the other variable in comparing the catch per day with either horsepower-length ratio or age of vessel.

The coefficient of partial correlation of catch per day and horsepower-length ratio, with age of vessel fixed, was +0.686. The coefficient of partial correlation of catch per day and age of vessel, with horsepower-length ratio fixed, was −0.497. Squaring the two partial-correlation coefficients shows that 47 percent of the variability in catch per day was due to differences in the horsepower-length ratio of the vessels and an additional 25 percent of the variability was due to differences in age of the vessels, leaving only 28 percent of the variability in catch per day unaccounted for.

In obtaining a more accurate method of rating each boat according to its fishing ability, both age of vessel and horsepower-length ratio were taken into account. For each boat, the amount in standard deviations that it varied from the mean of the horsepower-length ratio was obtained. The same was done for age of vessel. The two figures were then combined, but the age ratio was weighted by 0.52, the ratio of its influence on the catch to the influence of power.

The correlation of this adjusted rating of the individual boats with their catch per day of fishing gives a correlation coefficient of +0.817. Squaring the coefficient shows that the differences in the adjusted ratings of the vessels accounts for 67 percent of the variability in the catch per day.

This accounts for all but 33 percent of the variability in catch per day, agreeing closely with the 28 percent shown by the two coefficients of partial correlation.

Because such a large proportion of the variability in catch per day is due to the age and power of the vessel, it was obviously incorrect to introduce new boats into the calculation. Therefore, it was decided to reject the data from all vessels except 16 that fished continuously from 1932 through 1938. The use of the same boats every year meant that variations due to age and power of vessel could be held to a minimum. Whether the correlation between age of vessel and catch per day was due to obsolescence or to the increased efficiency of the newer boats cannot be deduced from the correlation. It is safe to say, however, that at least a large share of it is due to improvements other than power in the design of the newer boats.

ADJUSTMENT FOR CATCHING ABILITY OF TWO GROUPS OF OTTER TRAWLERS

As a preliminary step in analyzing the catch per unit of fishing effort in various areas and at various seasons it was desirable to determine the relative catching ability of the two groups of otter trawlers. This was to make possible the pooling of their catches so that one final curve of abundance could be obtained for each area.

The data for this comparison were obtained by determining the ratio of the catches of the larger-sized vessels (group B) to the smaller-sized vessels (group A) for each month in each individual subarea and depth zone for each year during the period 1932–38, whenever each group was represented by not less than 20 days of fishing. The result gave us 52 ratios for comparison. Because the final desideratum was a measure of abundance for all years and seasons, regardless of the amount of fishing conducted therein, these ratios were used without weighting.

For Subarea XXII J (medium depth), ratios were available for 6 years (all except 1934) for the months of July, August, and September. Testing the variance between the means of the 3 months against the variance within months (see Snedecor, 1940) showed no statistical difference in variance ($F=\frac{198.4}{31.5}=6.30$, whereas P of $0.05=19.42$).
This indicates no seasonal difference in the ratio of catching ability of the two groups of vessels during this period.

A further test was applied to the same data (Snedecor 1940), in which the variance between the means of the 6 years was compared with the variance remaining after accounting for that between the means of the 3 months ($F=\frac{303.5}{145.9}=2.08$, whereas P of $0.05=4.75$),
which showed that the differences between the years were not significantly greater than could be expected from random sampling.

As a final test, all 52 ratios were grouped into 7 annual samples. The proposition that the distribution of all years could have been drawn from the same population by random sampling was then tested by comparing the variance between the means of the annual samples with the variance within the samples ($F=\frac{355}{238}=1.41$, whereas P of $0.05=2.31$).
The result showed that there was no significant difference between the mean ratios of different years.

As the data do not indicate any significant seasonal or annual differences in the ratios of fishing ability of the two groups, the average ratio of all 52 comparisons, 0.887 ± 0.0217, has been used as the ratio. In order to pool the catches for the two groups of otter trawlers, the number of days fished by group-B boats has been decreased by 11 percent to make the fishing days comparable to group-A fishing days.

DEPTH ZONES

SELECTION OF THE ZONES

The depth of water sharply limits the distribution of many species. Obviously, the abundance of such a species cannot be accurately estimated by using the unweighted average catch per fishing day if the species varies in abundance according to depth. For this reason, the data have been analyzed by depths.

It was impractical to divide the banks by narrow depth bands, because the vessels usually fish over a range of several fathoms. After making preliminary plots of the depths fished by large otter trawlers, it was decided to employ three depth zones: shallow, 0 to 30 fathoms; medium, 31 to 60 fathoms; and deep, 61 fathoms and more.

As a check on the validity of the three bands selected, the depths that the captains or mates hailed as having been fished were plotted for 1933 and 1938 for a selected group of large otter trawlers in Area XXII South (Georges Bank and South Channel). The number of days fished (to the nearest tenth) was allocated to each 5-fathom zone. Thus, if a boat fished for 5 days in water from 55 to 65 fathoms, 2½ days were credited to the 56- to 60-fathom depth category and 2½ days to the 61-to-65-fathom depth. An overlap of only 1 fathom into another 5-fathom zone was disregarded, because the hailed depths, being only estimates, are not accurate within narrow limits. Figures 2 and 3 show, for these two samples, both the total number of days fished (as hailed) in each 5-fathom depth category and the number of days classified as shallow, medium, and deep, as used in our study.

Variations between the depths hailed and the depths used are due to three factors: (1) Minor inaccuracies in depth hails; (2) the fact that a vessel occasionally fished chiefly in one zone but also fished for a small portion of the time in another depth zone, without being able to give sufficient information about the species caught at each depth to permit splitting of the trip into

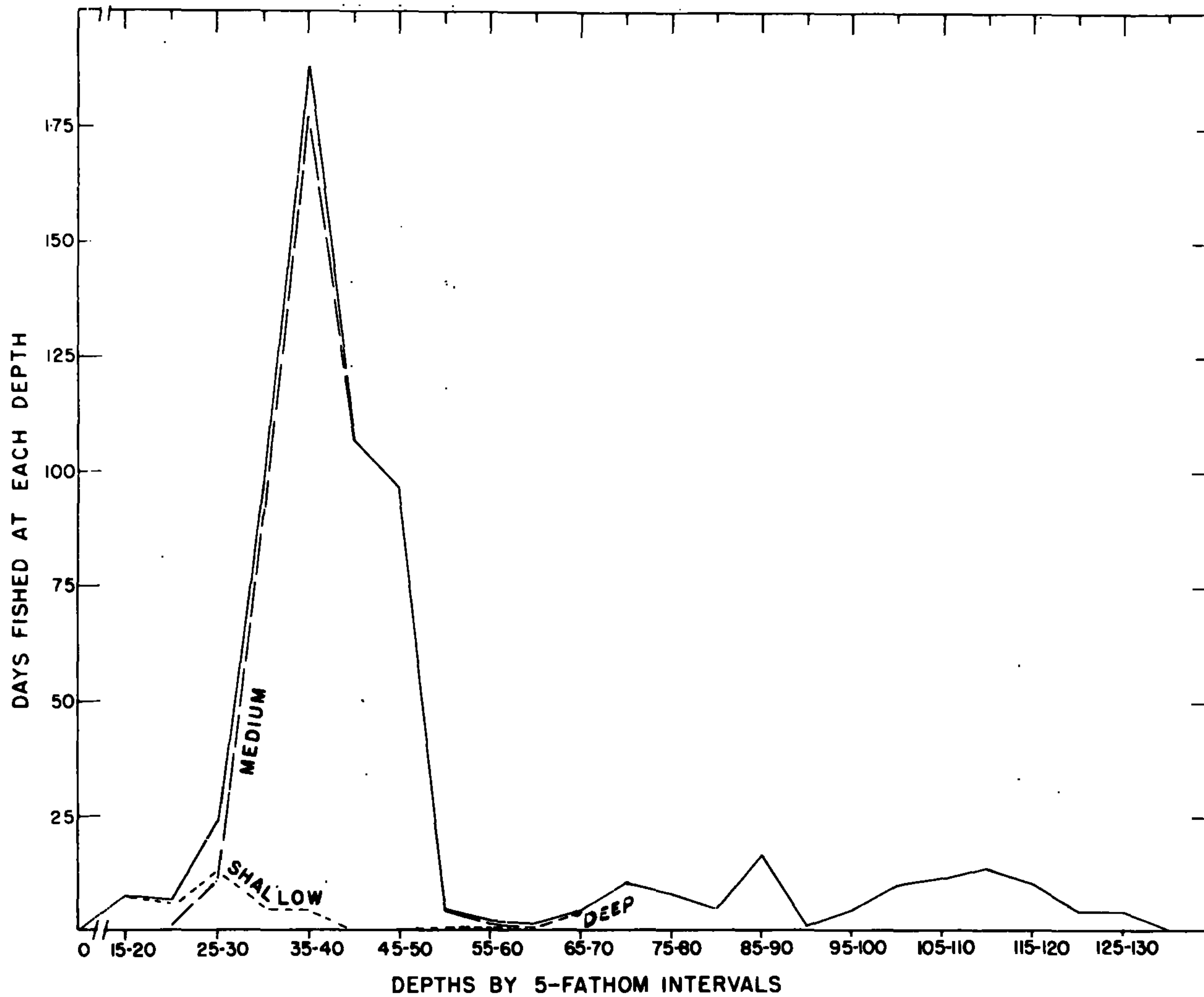

FIGURE 2.—Number of days fished at hailed depths in Area XXII (solid line) and number of days of fishing that falls into the three depth zones in [our] analysis for group B of large otter trawlers during 1933 (dotted and dashed lines).

two portions; and (3) the hailing of a depth not in accordance with the depth of water available at the indicated position (for instance, a vessel may hail 50 to 75 fathoms at a position where maximum depth is 60 fathoms).

The 60-fathom contour affords a well-defined breaking point between medium- and deep-water fishing, but the 30-fathom break between shallow and medium water is not so well defined. This is partly due to the fact that the 30-fathom contour in Area XXII South occurs chiefly on gradually shelving bottom, whereas the banks tend to drop off steeply at 60 fathoms. In spite of the difficulty of accurate determination, the shallow-water depth zone has been retained because some species, especially the yellowtail flounder, the blackback, and the lemon sole, are much more abundant in these shallow waters.

The depth zones also help in isolating the fishing effort directed toward the catching of ocean perch because the bulk of them are taken at depths of more than 70 fathoms.

AMOUNT OF FISHING BY OTTER TRAWLERS IN EACH DEPTH ZONE

The amount of fishing effort expended in each depth zone was determined from more than 32,000 days of fishing by otter trawlers of more than 50 gross tons, covering the period from 1928 to 1937, inclusive (except 1931). These days of fishing were plotted on the chart by unit areas (10′ of

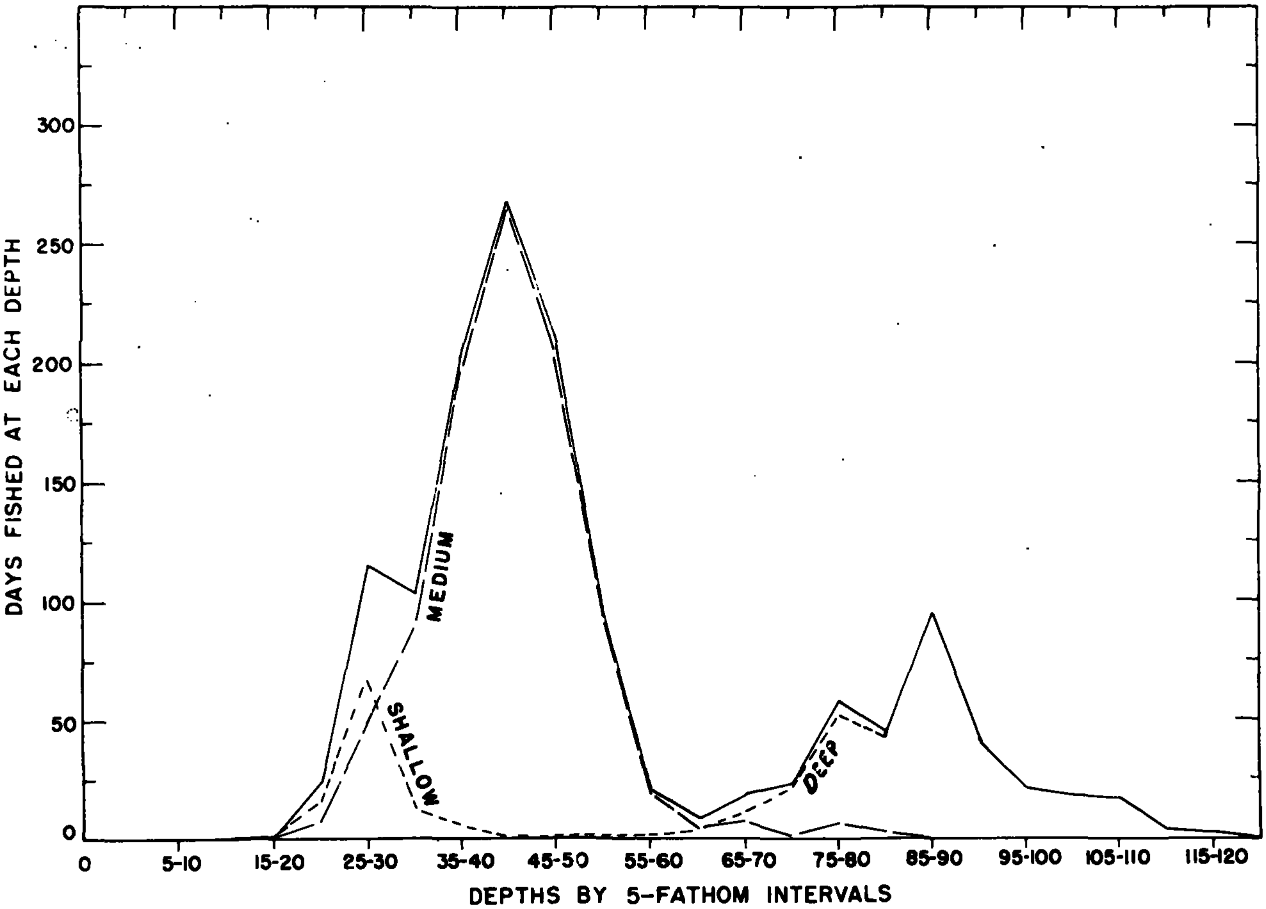

Figure 3.—Number of days fished at hailed depths in Area XXII (solid line) and number of days of fishing that falls into the three depth zones in [our] analysis for group B of large otter trawlers during 1938 (dotted and dashed lines).

latitude and 10′ of longitude, or roughly 10 miles by 7.5 miles, or 75 square miles).

A first estimate of the fishing in each depth zone was made by assigning an average depth to each unit area from the soundings appearing on the charts, assuming that all fishing in that unit area was at the average depth of the unit area (depths of more than 125 fathoms were disregarded). This tabulation showed 23.8 percent of the fishing in the shallow zone, 52.0 percent in the medium-depth zone, and 24.2 percent in the deep zone.

Next, a more accurate estimate was obtained by constructing contours of fishing intensity in Area XXII South. In constructing contours of fishing intensity it was not feasible merely to interpolate from one unit area to another by using the total days of fishing in each unit area as the intensity in the center of that unit area, because the days of fishing in each unit area really represent the average for the whole unit area and not for any particular point. The method finally adopted was to construct frequency polygons of days of fishing across the entire Area XXII from north to south and from west to east for each column and each row of unit areas. These frequencies then were smoothed so that the amount under the curve would average the correct number of days of fishing in each unit area.

After the fishing-intensity contours had been drawn (see fig. 4), the area of shallow, medium, and deep water within each contour was measured with a planimeter. Multiplying the midpoint in the range of fishing intensity within contour lines by the areas enclosed gave a total of 32,479 fishing days, compared with 32,127 in the original data, an error of only slightly over 1 percent. By this

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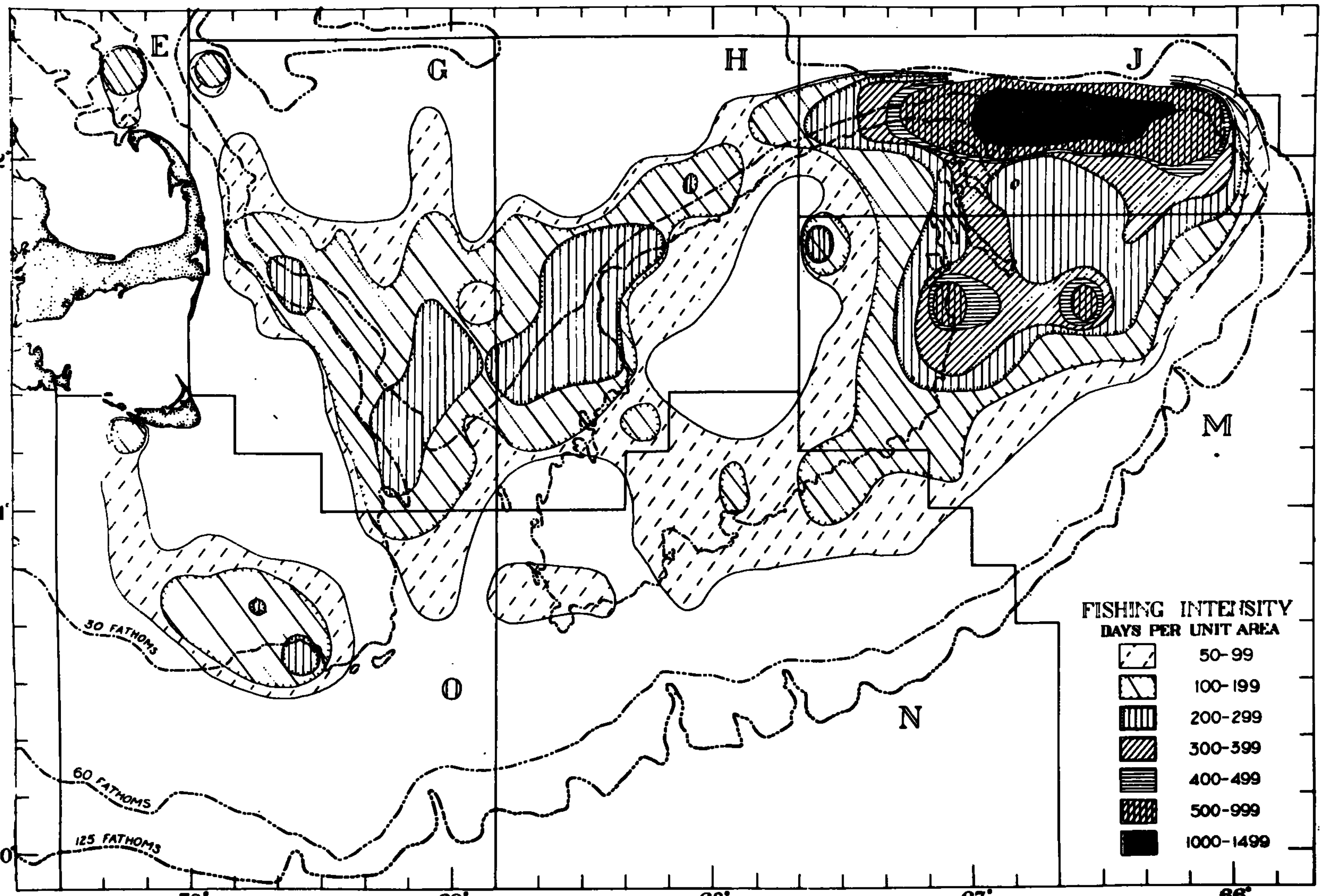

FIGURE 4.—Contours of fishing intensity per unit area (see text) by otter-trawl vessels of more than 50 gross tons in Area XXII South (Georges Bank and South Channel), constructed from plots of 32,127 days of fishing during 1928 to 1937, inclusive (except 1931).

method, the proportion of days fished in each zone was 23.4 percent for shallow, 53.0 percent for medium, and 23.6 percent for deep, which agreed very closely with the proportions derived from the first rough estimate.

TOTAL AREA AND PRODUCTIVE AREA OF BANK IN EACH DEPTH ZONE AND SUBAREA

On Georges Bank and South Channel, each unit area (10′ of latitude by 10′ of longitude) averages 10 by 7.5 miles, or 75 square miles in area. On this basis, using our own 60- and 125-fathom contour lines, the whole of Area XXII South contains 22,153.5 square miles of bank ranging between 0 and 125 fathoms in depth. Of this total, 29.5 percent is in the shallow zone, 41.2 percent is in the medium-depth zone, and 29.3 percent is in the deep zone (not considering depths of more than 125 fathoms).

Table 1 shows the square miles of bank at each depth in each subarea. The right-hand section of the table shows the area of productive bank, as measured by the intensity of the otter-trawl fishery. The productive area is interpreted to include the portions of the bank enclosed by the fishing-intensity contour of 50 days per unit area out of a total of more than 32,000 fishing days. Studies on the haddock (Herrington 1948) show that the area occupied by the schools of large haddock expands in years when the population is large and contracts when the population shrinks. Therefore, there are large areas (especially in Subareas M, N, and O) that are potentially productive, as shown by the abundance of haddock taken in former years, that have been fished less in recent years. However, such portions of the banks must be included in any estimate of the productive area.

In figure 5, the areas of bank in each depth zone are shown graphically. It is noteworthy that subareas G and H on the west and east sides of the South Channel contain less than 20 percent of medium-depth water although they have approximately twice as much shallow water and three to four times as much deep water. Thus, the medium-depth zone is a narrow, rapidly shelving band between the shallow bank and a deep-water plateau that occupies the center of the South Channel. The deep water in the other four subareas, instead of forming a plateau, is a narrow shelving rim surrounding Georges Bank.

The deep-water zone of G and H on the plateau (chiefly about 70 to 95 fathoms) is fished intensively for ocean perch, gray sole, and haddock. The narrow band of deep water comprising the northern portion of J, and sometimes extending slightly into M, has practically no ocean perch but is fished intensively for haddock and other groundfish.

The deep zone on the eastern and southern edge of Georges Bank in M, N, and O is seldom fished. The reason for the lack of fish in this area may be the influence of the Gulf Stream, which comes close to this edge of the bank and causes a rise in temperature.

Except for G and H, all of the subareas contain more medium water than either shallow or deep. Practically all of the medium-depth water in J and the western portion of M is heavily fished for haddock, cod, and flounders. Subareas N and O were not so heavily fished because of the lack of sufficient population pressure in the haddock in recent years (as explained above), but both subareas contain large areas of potentially productive bank in the medium-depth zone.

TABLE 1.—*Approximate area and fishing intensity by otter trawlers in each depth zone and subarea of Area XXII South*

Subarea	Bank area (square miles)				Productive area (square miles)[1]			
	Shallow (0–30 fath.)	Medium (31–60 fath.)	Deep (61–125 fath.)	Total (0–125 fath.)	Shallow (0–30 fath.)	Medium (31–60 fath.)	Deep (61–125 fath.)	Total (0–125 fath.)
G	932.25	491.25	2,175.00	3,598.50	321.00	456.00	1,150.50	1,927.50
H	1,239.75	603.75	1,840.50	3,684.00	575.25	543.75	757.50	1,876.50
J	430.50	976.50	694.50	2,101.50	406.50	975.00	497.25	1,878.75
M	969.00	2,318.25	329.25	3,616.50	871.50	1,620.00	0.00	2,491.50
N	969.00	2,266.50	795.00	4,030.50	620.25	707.25	0.00	1,327.50
O	1,990.50	2,465.25	666.75	5,122.50	755.25	379.50	0.00	1,134.75
Total	6,531.00	9,121.50	6,501.00	22,153.50	3,549.75	4,681.50	2,405.25	10,636.50
Percent	29.48	41.17	29.35	100.00	33.38	44.01	22.61	100.00

[1]Areas enclosed by fishing-intensity contour of 50 days of fishing per unit area of 75 square miles, out of a total of over 32,000 days of fishing.

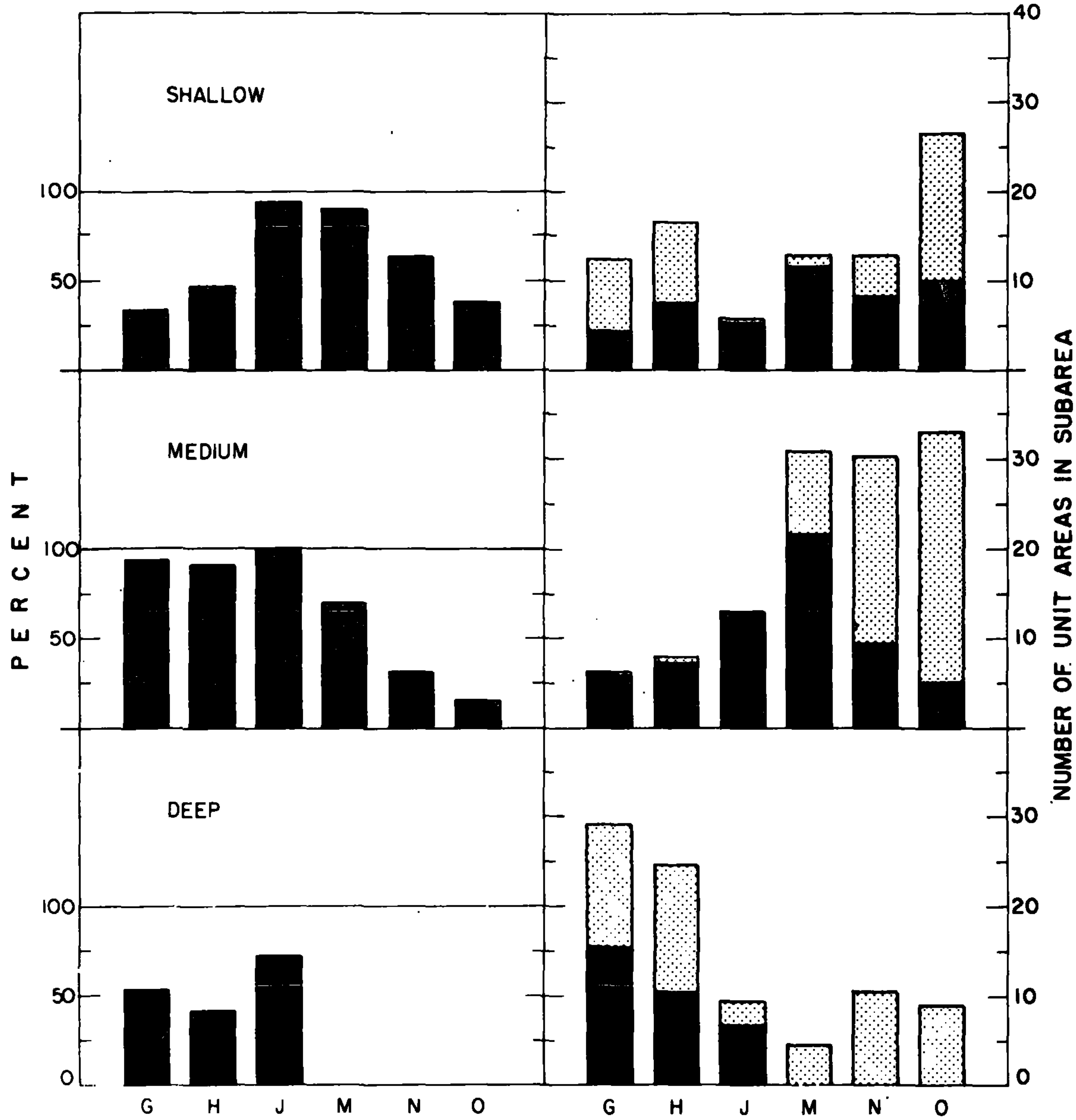

FIGURE 5.—Areas of shallow, medium, and deep water in the subareas of Area XXII South, and the proportion considered productive (using the contour of 50 days of fishing per unit area as a criterion). Left-hand side shows percent of productive area in each subarea. Right-hand side shows productive (black) and nonproductive (stippled) areas in each subarea.

The productivity of the shallow zone is in reality somewhat higher than is indicated by the data, because these portions of the bank are often avoided in stormy weather and they are not heavily populated with cod or haddock except at certain seasons. However, this zone contains an abundance of blackbacks, lemon sole, and yellowtail flounders.

DISTRIBUTION OF DIFFERENT SPECIES ACCORDING TO DEPTH ZONES

Before intelligent measures can be formulated in a fishery-management program, it is highly desirable, and usually necessary, to be able to estimate the abundance of the population. For a species that forms the principal object of a fishery, such as haddock, the changes in the catch per day of a unit of fishing effort may give close estimates of the abundance. However, for the species that are caught incidentally while fishing for another species, no such assumption can be made without careful study. Shifts in the depth or locality fished in pursuit of the principal species may yield changes in the catch per unit of fishing effort of the minor species that cannot be interpreted as changes in abundance without a knowledge of the depth and areal distribution of those species.

In order to discover the relative abundance of each species in different depth zones, the catch per unit of fishing effort was calculated for each species, in each depth zone, for each year from 1932 to 1938. In this analysis, only "pure" trips were used—that is, trips in which the entire catch was taken in the same depth zone and subarea. This was essential, because in "mixed" trips one must depend wholly on the fisherman's recollection of what proportion of each species was caught in each depth zone. Because of the variety of fishes in a normal catch it is impractical to obtain this information for all of the minor species.

In analyzing these data, only the Georges Bank area was used for two reasons: (1) The data from other areas were too scattered; and (2) it was hoped that, by confining the analysis to a relatively small area, variations in the data arising from including various populations of the same species would be reduced to a minimum.

For the shallow zone (0–30 fathoms), all of the shallow fishing in Subareas XXII H, J, M, N is included. This forms the shallow areas of Georges Bank.

For the medium depth zone (31–60 fathoms), Subareas XXII H, J, and M are included. The fishing on Subarea XXII N was only occasional, so this subarea was excluded. The medium-depth fishing in Subareas XXII G and XXII O was excluded because of differences in conditions and populations. For instance, the "blackbacks" in Subareas XXII H, J, and M are young lemon sole, while in Subareas XXII G and XXII O they are the true blackback.

For the deep zone (more than 60 fathoms), Subareas XXII G, H and J are included.

In order to discount changes in abundance or availability of different species during the 7-year period (1932–38), it was decided to average the ratios between the catch per day in each depth zone, not the actual catch per day. The following tabulation shows the number of standard days fished and the total catch in each depth zone during each year.

Year	Days of fishing (number)			Catch of all species (thousands of pounds)		
	Shallow zone	Medium zone	Deep zone	Shallow zone	Medium zone	Deep zone
1932	139.3	816.3	429.8	2,410	16,160	7,226
1933	51.5	621.4	203.5	937	10,626	2,581
1934	20.4	308.4	41.1	348	5,146	566
1935	35.7	503.7	81.3	575	9,205	2,416
1936	41.5	623.1	69.0	1,034	14,421	2,134
1937	20.4	654.9	166.5	415	14,948	3,053
1938	12.4	501.1	96.7	476	10,023	2,719
Total	321.2	4,028.9	1,087.9	5,927	65,580	20,694

Since the medium-depth zone was well represented in each year, it was used as a standard, and the ratio of the catch of each species in both shallow and deep zones to the catch in the medium-depth zone was calculated for each year.

The geometric means of the ratios were then calculated. Thus if

a=catch of a species in shallow (or deep) zone,

b=number of standard days fished in shallow (or deep) zone,

k=catch of a species in medium-depth zone,

m=number of standard days fished in medium-depth zone,

y=any individual year, and

x=geometric mean ratio of availability of a species in shallow (or deep) zone to the availability in the medium-depth zone,

then

$$\log X = \frac{\log\left(\frac{\frac{a}{b}}{\frac{k}{m}}\right)_{y1} + \log\left(\frac{\frac{a}{b}}{\frac{k}{m}}\right)_{y2} + \cdots + \log\left(\frac{\frac{a}{b}}{\frac{k}{m}}\right)_{yn}}{\sum_{y=1}^{n} y}$$

There might be some question about the advisability of using an unweighted average instead of a weighted average in obtaining these geometric-mean ratios. At this point it must be remembered that in such a chronological series, weighting of the data (thus giving much more weight to certain years) may introduce a bias which we cannot measure. Using the logarithms of the ratios, an analysis of variance was made, which showed no significant difference between the means of the years; therefore the years were averaged without weighting.

From the analysis of the variance of the logarithms of the ratios, the least significant mean difference ($P=.05$) between ratios was calculated for the mean ratios of the species in the shallow zone and in the deep zone (Snedecor 1940, p. 344); these are shown in table 2. Examination of table 2 reveals that the difference in availability is usually statistically significant for any two species at the same depth.

The relative abundance (availability) at each depth is shown in figure 6. In interpreting this figure it must be borne in mind that the chief object of this otter-trawl fishery by large vessels has been haddock. Thus, the sample of data used in this table comprises a total of 5,437 corrected days of fishing with a catch of 92,201,000 pounds. Of this total, 43.4 percent, or 39,955,000 pounds was large haddock, and 29.2 percent, or 26,914,000 pounds was scrod haddock, making a total of 72.6 percent haddock.

Since haddock was the principal object of this fishery, the fleet concentrated where haddock could be taken in greatest abundance. Thus, the fact that the fleet spent most of its time in water of medium depth would indicate that the haddock is most often found at that depth. When the haddock move into shallow water for a

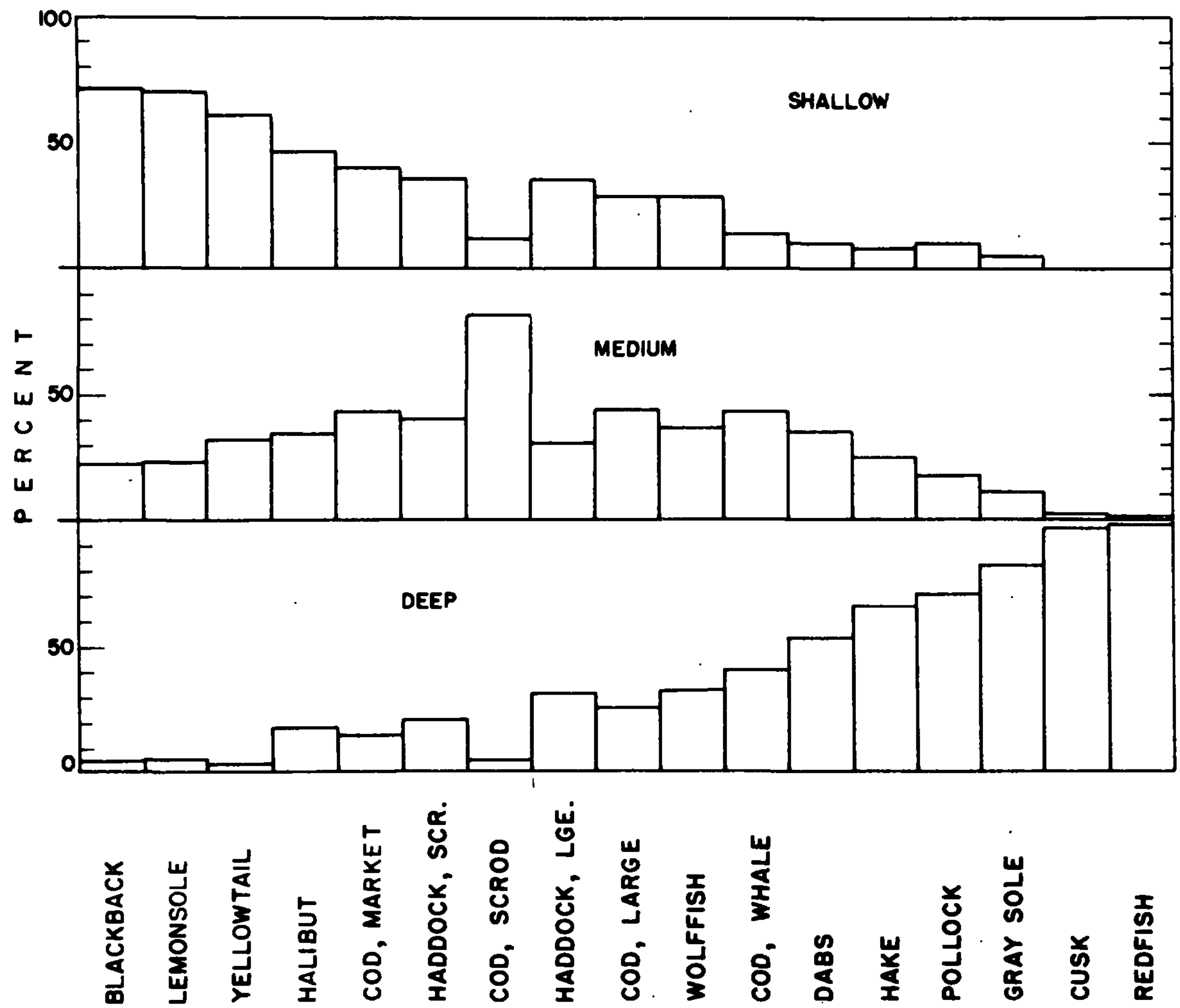

FIGURE 6.—Relative abundance of each species of groundfish in each depth zone in Area XXII South, from otter-trawl catches.

TABLE 2.—*Distribution of species of groundfish according to depth zones on Georges Bank, 1932–38*

Species	Market size (pounds)	As ratio of medium depth		As percent at each depth		
		Shallow zone	Deep zone	Shallow zone	Medium zone	Deep zone
Blackback		312.6	22.4	71.86	22.99	5.15
Lemon sole		303.1	24.2	70.93	23.40	5.66
Yellowtail		187.2	12.6	62.44	33.36	4.20
Halibut		129.1	54.3	45.55	35.29	19.16
Haddock (large)	Over 2½	113.7	101.2	36.11	31.76	32.14
Cod (market)	2½ to 10	91.5	35.0	40.40	44.15	15.45
Haddock (scrod)	Under 2½	89.1	54.0	36.65	41.14	22.21
Wolffish		78.7	88.3	29.48	37.45	33.07
Cod (large)	10 to 25	65.9	58.9	29.31	44.48	26.21
Pollock		57.6	389.9	10.52	18.26	71.21
Gray sole		41.0	671.4	5.05	12.31	82.64
Cod (whale)	Over 25	31.8	93.8	14.10	44.33	41.58
Hake		30.9	261.2	7.88	25.50	66.62
Dabs		28.7	148.6	10.35	36.06	53.59
Cod (scrod)	1½ to 2½	15.3	6.4	12.57	82.17	5.26
Cusk			3,917.0		2.49	97.51
Redfish (ocean perch)			6,607.0		1.49	98.51
All species		106.4	106.9	33.96	31.92	34.12
Least significant mean difference of ratio (P=.05)		3.7	4.2			
Total days fishing (standard group-A days. See text)				321.2	4,028.9	1,087.9
Total fish landed (in thousands of pounds)				5,927	65,580	20,694

short time, the fleet follows them. Because we get catches from shallow water only for the period that the fleet is there (when haddock are abundant), it appears as though haddock are equally abundant in shallow and in medium-depth water, but such is not the case.

According to figure 6, the smaller sizes of haddock tend to be less abundant in deep water, but the true difference between the depth zones for this species may be more pronounced than the data indicate.

In the case of pollock, the data are somewhat misleading. The otter trawlers make a few large catches of pollock in deep water in the fall and winter months, when the pollock are concentrated in dense schools, but these fish are caught only incidentally to the pursuit of haddock during the remainder of the year. Thus, although the data indicate that the pollock is chiefly a deep-water species, pollock are known to frequent all depths. For example, along the Maine coast the pollock school at the surface and are captured by small purse-seine boats.

SUMMARY

1. The fishing intensity, by areas and depths, by otter trawlers during a period of 10 years (1928 to 1937, except 1931) was determined for Georges Bank, Subareas XXII, G, H, J, M, N, and O. The information was obtained from plots of more than 32,000 days of fishing by otter trawlers of more than 50 gross tons.

2. During the 10-year period, the otter trawlers fished 23.4 percent of their time in water of 0 to 30 fathoms in depth, 53.0 percent in water of 31 to 60 fathoms in depth, and 23.6 percent in waters of more than 60 fathoms.

3. During the 10-year period, the productive areas amounted to 54.3 percent of 6,531 square miles of shallow area (0–30 fathoms), 51.3 percent of the medium-depth area (31–60 fathoms) of 9,121.5 square miles, and 37 percent of the area of 6,501 square miles of deep area (61 to 125 fathoms).

4. The relative abundance of each species of groundfish in each depth zone was determined from 5,437 standard otter trawler days of fishing, landing 92,201,000 pounds of groundfish from 1932 to 1938 inclusive.

5. The shallow zone was the center of abundance for blackback, lemon sole, and yellowtail flounders. The medium zone was the center of abundance for scrod cod (1½ to 2½ pounds). The deep zone was the center of abundance for ocean perch, cusk, gray sole, pollock, hake, and dabs. Halibut, wolffish, haddock, and cod of more than 2½ pounds did not differ widely in abundance between depth zones.

6. Because of the differences in relative population densities between depth zones, the catch per unit of fishing effort cannot be used as a measure of abundance for most of the species, unless it is tabulated by depth zones.

7. In order to obtain usable indexes of abundance for certain of the species, it may first be

necessary to obtain accurate estimates of the area occupied in each depth zone to permit proper weighting of the index for each depth zone according to the proportion of the population represented. This areal distribution cannot be obtained from the records of the commercial fishery. Therefore, final abundance indexes depend upon surveys of distribution by a research vessel. Such data have been obtained for recent years and are in process of analysis.

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